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GB 1222963 A EP 0288215 A

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On-line databases: WPI, CLAIMS

(54) Measuring the impedance of a lossy capacitor

(57) A lossy capacitor (Fig. 1 not shown) is charged and discharge cyclically (a). The current flowing through the capacitor is measured at different parts of the cycle by switching it between two separate measuring points. A first current measurement is made during a first part of the cycle during charge (b) and this is representative of the capacitive component of impedance. A second current measurement is then made when only a residual current flows through the capacitor when fully charged (c) and this is representative of the conductive component of impedance. The method may be used for example to detect the moisture content of a material e.g. breakfast cereal, to monitor the uniformity of a material, or in electrical capacitance tomography.

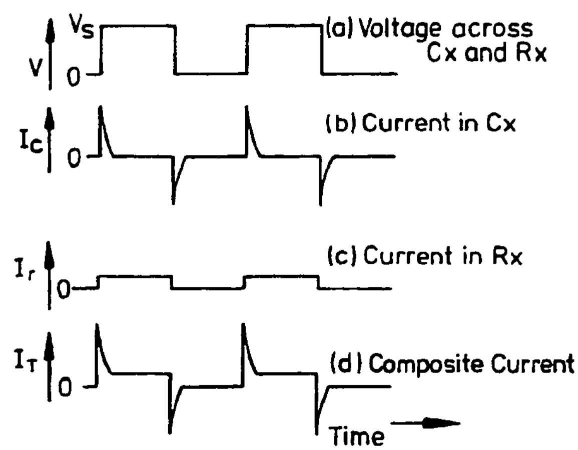

FIG.2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1990.

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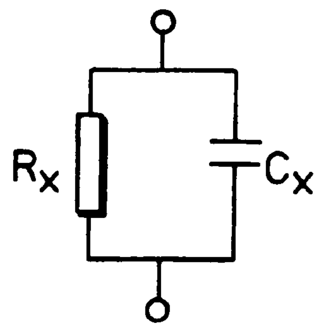
Rx
Cx

FIG.1

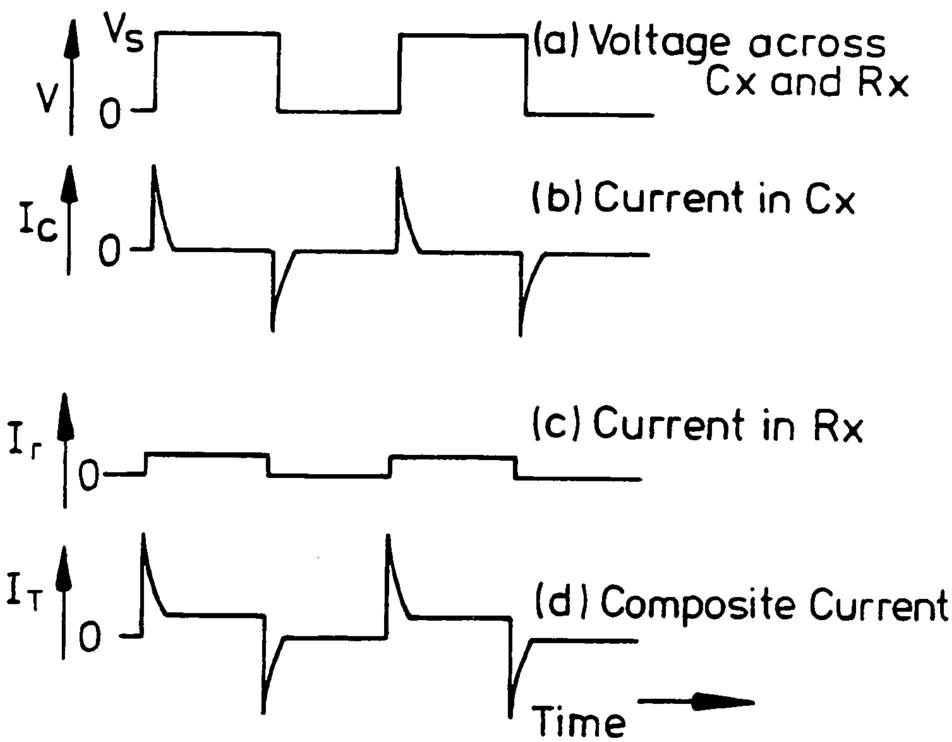
Vs
V
0
(a) Voltage across Cx and Rx
Ic
0
(b) Current in Cx
Ir
0
(c) Current in Rx
IT
0
(d) Composite Current
Time

FIG.2

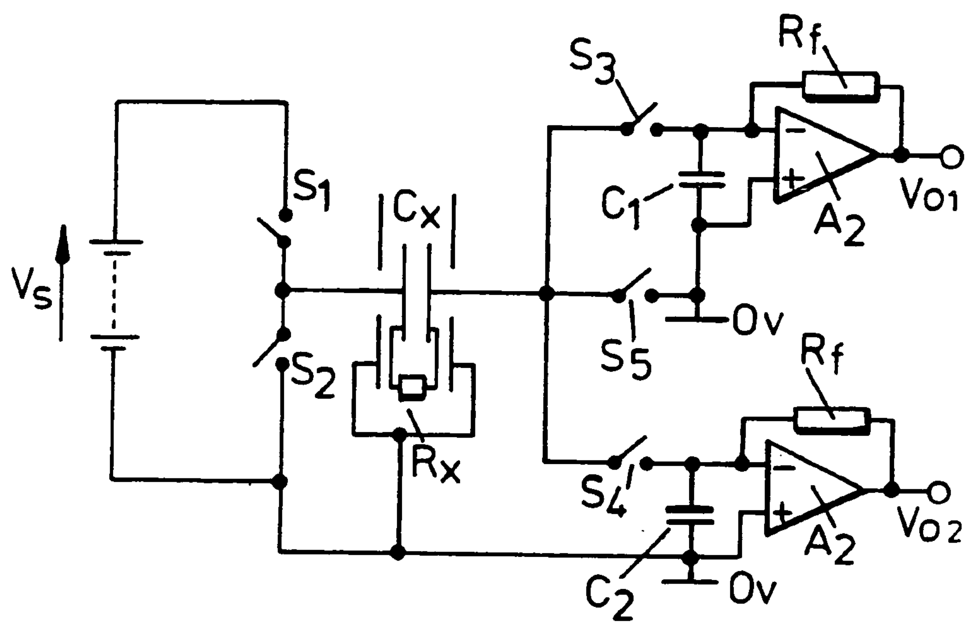

FIG.3

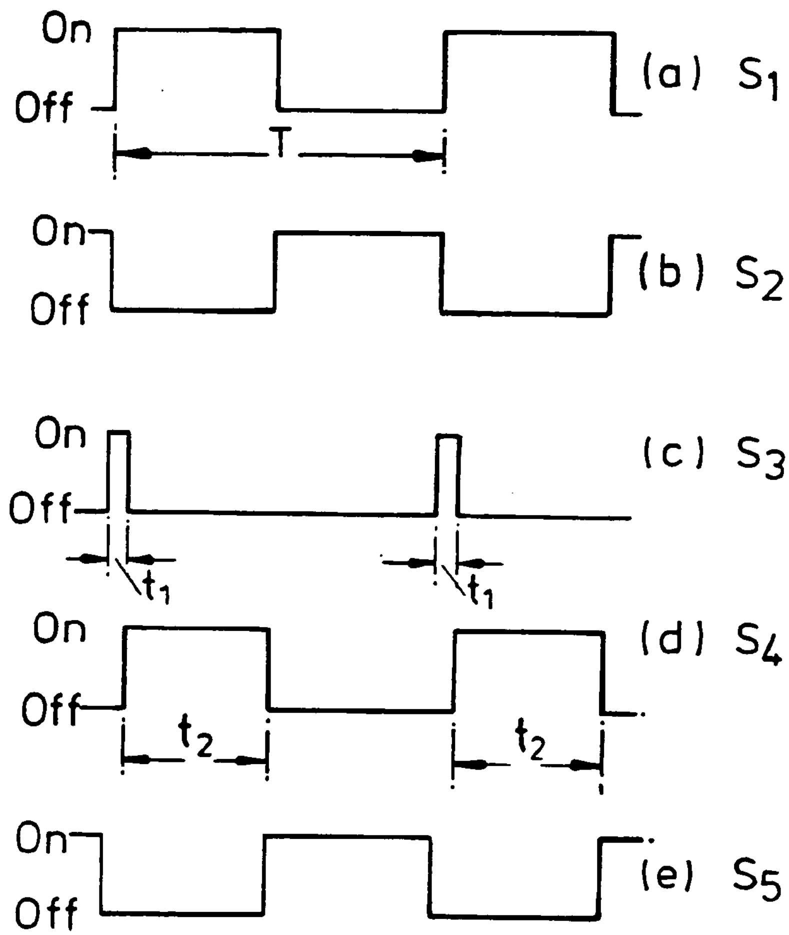

FIG. 4

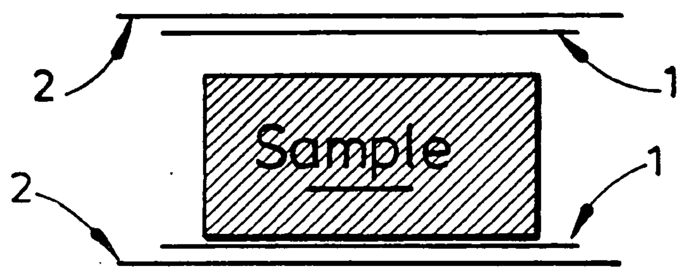
Sample
1
1
2
2

FIG. 5

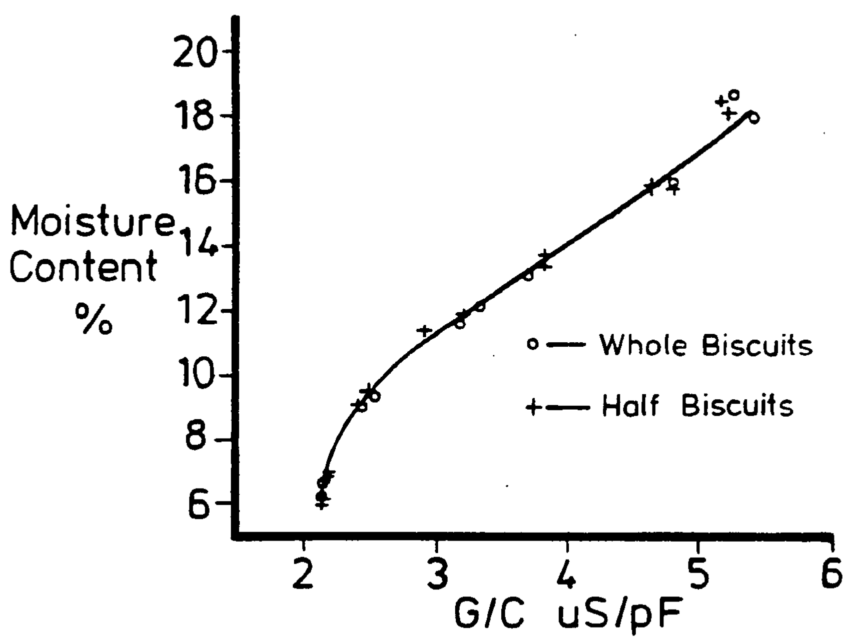
Moisture Content %
20
18
16
14
12
10
8
6
2
3
4
5
6
G/C uS/pF
o— Whole Biscuits
+— Half Biscuits

FIG. 6

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A METHOD AND APPARATUS FOR MEASURING THE IMPEDANCE OF A LOSSY CAPACITOR

The present invention relates to a method and apparatus for measuring the impedance of a lossy capacitor.

It is often necessary to measure very small values of capacitance, of the order of picofarads, in situations where there may also be larger stray capacitance to earth. This situation may occur, for example, where screened capacitive electrodes are used as sensors and the unknown capacitance to be measured is that of a material placed between two sensor plates.

One known method of making such small measurements of capacitance is the Charge Transfer Method. This uses the technique of alternately charging and discharging the capacitor under test in a repetitive manner and measuring the current which flows therethrough.

The Charge Transfer Method has the advantages of virtual immunity to the effect of stray capacitance and rapid measurement of the capacitance. However, the method is only suitable in applications where the capacitor under test is loss free. In practice a capacitor will often have finite conductance and its impedance comprises capacitive and conductive components. The existing Charge Transfer Methods do not take account of the effect of the conductive component of the capacitor on the measured value of capacitance and the capacitance measurement is accordingly inaccurate. It is an object of the present invention to obviate or mitigate the aforesaid disadvantage.

According to the present invention there is provided a method for measuring the impedance of a lossy capacitor comprising the steps of cyclically charging and discharging the capacitor, measuring the current flowing through the capacitor at different times in the cycle to establish values of current resulting from the capacitive component and the conductive component of the impedance and converting the current values into capacitive and conductive components of impedance.

Preferably the period of the charge or discharge cycle is chosen to be substantially greater than the estimated time required to charge or discharge the lossy capacitor, a first current measurement being

made at the beginning of the cycle when the capacitor is being charged or discharged and a second current measurement being made subsequently to determine the residual current flowing as a result of the conductive component of the impedance.

Conveniently the measuring of current at different parts of the cycle is achieved by timed switching of the current flowing between two measuring points so that the first current measurement is measured at a first measuring point and the second current measurement flowing is measured at a second measuring point.

The measurements may be taken during the charge or discharge cycle or both. In the latter case the results may be compared in a differential made to eliminate errors in components of an electrical circuit or those caused by the environment.

A specific embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 represents an equivalent circuit for a lossy capacitor;

Figure 2 shows current and voltage waveforms for the lossy capacitor of figure 1;

Figure 3 is a circuit diagram of a measuring circuit operating in accordance with the method of the present invention;

Figure 4 shows control signal diagrams relating to switch operations in the circuit of figure 3;

Figure 5 shows schematically one application of the present invention; and

Figure 6 shows a graph of moisture measurements taken using the circuit of figure 3 in the application shown in figure 5.

Referring now to the drawings, an equivalent circuit of a lossy capacitor is shown in figure 1 as a parallel combination of resistance R_x and capacitance C_x.

When it is desired to measure the capacitance of a lossy capacitor the presence of resistance R_x will cause a current to flow into a measuring circuit in addition to the current due to the capacitance and errors will occur in the measurement of capacitance if it is assumed that all the current flows into the capacitance. When a pulsed voltage (denoted V in figure 2(a)) is applied to the capacitor a typical measuring circuit will monitor the resultant waveform as

shown in figure 2(d). The current I_c through the capacitor C_x consists of positive (charging) and negative (discharging) pulses of current as shown in figure 2(b). The time constant of these pulses is determined by the value of C_x and the impedance of the charging source. The value of C_x is normally low (typically less than a few nanoseconds) compared with the pulse frequency.

When a capacitor is lossy, there is also a constant component of current I_r which flows through the equivalent resistance R_x as shown in figure 2(c). Thus, the total current I_T through the lossy capacitor as represented by the graph of figure 2(d), consists of short pulses of current while the capacitive component C_x is being charged, superimposed on a constant current which flows through the resistive component R_x during the charging cycle.

In contrast to known charge transfer measurement techniques the present invention distinguishes between the two components of current. This is achieved by the measuring circuit shown in figure 3.

The capacitor to be measured is shown as its equivalent circuit C_x,R_x and is connected to a power supply of voltage V_s via analog gate switches S1 and S2. The other terminal of the capacitor is connected via analog gate switches S3,S4 and S5 to the inputs of operational amplifiers A_1, A_2 or to ground. Each amplifier has a capacitor C_1,C_2 connected across its input terminals. The values of C_1 and C_2 are chosen to be significantly greater than that of C_x. Each amplifier has a feedback resistor R_f.

Figure 4 shows the sequence of control signals applied to the circuit by means of switches S1 to S5. For convenience the signals are shown to be sequential. In practice, to avoid the possibility of simultaneous conduction of some of the switches, a small time delay must be allowed between operating consecutive switches. The symbol T represents total time taken to charge and discharge the capacitor under test.

Initially S3 is closed for a period t_1 chosen to be several times longer than the estimated charging time of C_x. Simultaneously S1 is closed and C_x is charged via C_1. Switch S1 remains closed for the remainder of the charging cycle. Once C_x is fully charged, switch S3 is opened and switch S4 closed for the remainder of the charging cycle (t_2). The resistive component of the current I_r which remains for

the rest of the charging cycle (see figure 2(d)) flows into capacitor C_2. At the end of the charging cycle switches S1 and S4 are opened and switches S5 and S2 are closed to commence the discharge cycle. When the capacitor under test is completely discharged switches S5 and S2 are opened and the charging cycle is recommenced.

The above described charge and discharge cycles are repeated in sequence f times per second.

The theoretical output voltages V_{o1}, V_{o2} from the measuring circuit of figure 3 can be derived for the lossy capacitor as shown below.

During the charging cycle (S1 and S3 closed) the charge stored in C_x is given by the equation:

$$Q = C_x.V_s$$

As mentioned above, the current I_c which flows through C_x to establish this charge also flows into C_1. As C_1 is much larger than C_x, the voltage developed across C_1 is very small. By restricting the period t_1 to a value only a few times longer than the estimated charging time of C_x nearly all of the current which flows in C_1 is due to the charging of C_x. It will be noted that period t_1 is small compared with period t_2.

In the discharge cycle (S2 and S5 closed) C_x is completely discharged.

Charge is thus transferred to the capacitor C_1 f times per second and this represents an average current I_1 flowing into C_1 where:

$$I_1 = fC_xV_s$$

The operational amplifier A_1 attempts to maintain the potential at its inverting input at zero. It does this by injecting an equal and opposite feedback current I_f through resistor R_f and into C_1, where:

$$I_f = -V_{o1}/R_f$$

and V_{o1} is the output voltage of A_1.

Equating I_1 and I_f, the equation for the output voltage becomes:

$$V_{o1} = -f.C_x.V_s.R_f$$

Hence the output voltage of A_1 is a voltage proportional to the capacitance C_x under measurement. By restricting the current measurement to the period t_1 during which C_x is being charged the effects of conductance are almost completely eliminated.

The control signals of the switches operate so as to prevent amplifier A_2 from measuring any of the charging or discharging current. Amplifier A_2 simply measures the current which flows in R_x for the part of the charging cycle t_2 following the rapid charge or discharge of C_x.

The average current I_r flowing into C_2 from R_x during this period t_2 of the cycle (the period of which is represented by T) is given by:

$$I_r = (V_s/R_x).(t_2/T)$$

The amplifier A_2 maintains a virtual earth at its input by injecting an equal and opposite feedback current I_f through resistor R_f into C_2, where:

$$I_f = -V_{o2}/R_f$$

Equating the two currents I_f and I_r the equation for output voltage becomes:

$$V_{o2} = -V_s.(R_f/R_x).(t_2/T)$$

From this it can be seen that the output voltage of A_2 is proportional to the conductance $(1/R_x)$ of R_x.

It will be appreciated that the above described circuit is only an exemplary embodiment of how the desired measurements can be made. The same circuit has been used to measure the capacitive component and the resistive component of impedance to illustrate the principle of operation but obviously any circuit which produces an output proportional to the current which flows in the resistive

component of impedance of the capacitor under measurement, whilst maintaining a virtual earth at its input, can be used.

Two of the above described circuits could be used in parallel to compare two capacitors in a differential mode.

If the input to the measuring circuits is ac-coupled via a large blocking capacitor, a component of resistive current will be present in the discharge cycle. The components of current in the discharging cycle can be measured in a similar way (although the outputs of the capacitance and conductance circuits will now be positive) as described above. If both the charging and discharging cycles are used, the outputs of the charge and discharge circuits can be used in a differential mode. This has the advantage that the effects of drift and offset in the operational amplifiers are minimised.

The measuring circuit will be immune to stray capacitance as switches S1 to S5 ensure that the sensor plates of the capacitor are at all times connected to either a low impedance source or to ground.

In practice there will be some overlap in time of the currents resulting from the separate effects of capacitance and conductance, and there will be some residual interaction between these two measuring circuits. However, in many applications these effects will be negligible.

It will be appreciated that there are a number of alternatives to operational amplifiers for measuring the currents. For example, high speed digital sampling and signal processing techniques could be used to measure the charging and discharging currents directly. This would permit direct computer processing of the current or voltage waveforms.

The technique of measuring the conductive and capacitive components of impedance of a lossy capacitor has a number of applications. For example, the method can be used to determine the dielectric properties of materials placed between the electrodes of a capacitor by measuring the changes in capacitance and conductance which occur when the material is introduced.

If the dielectric material is homogeneous then, although the individual capacitance and conductance changes which occur will vary according to the amount of material present, the ratio of capacitance (C) to conductance (G) will be independent of the quantity of the

dielectric material introduced. Thus the ratio of C/G can be calculated from the measurements made on samples of varying size and mass. Such measurements will be repeatable, reliable and can be made on a sample basis or continuously in the case of material conveyed between the electrodes.

One application of this technique is the measurement of the moisture content of dielectric materials. An example is shown in figures 5 and 6 for breakfast cereal biscuits. A sample of the biscuit was placed between electrodes 1 of the capacitor which are screened by plates 2. Measurements of capacitance and conductance were made using the method of the present invention and the results are shown in the graph of figure 6. The graph shows measurements of the ratio C/G for biscuits of differing sizes and moisture content plotted against measured moisture content. The results indicate that the measurement of C/G can be calibrated to indicate moisture content directly, giving a figure which is independent of the sample mass or size. Measurements are shown for both whole and half biscuits, confirming that the technique is largely unaffected by the size of the sample.

The ratio C/G is independent of the quantity of dielectric material introduced between electrodes 1. Individual capacitance and conductance changes will vary according to the amount of material present but can nevertheless be used individually in calculation of the moisture content provided account is taken of the amount of material present.

Existing methods for measuring moisture content require biscuits to be ground up, a sample weighed and the moisture driven off by heating in an oven, after which the sample is re-weighed. The moisture content is assumed to be the difference in weight of the sample before and after drying. This process takes, typically, 24 hours before results are available. By comparison, the method of the present invention allows biscuit moisture measurements to be made at a rate exceeding 1000 per second. Moreover, the method is suitable for use on a production line, allowing immediate action to be taken if problems start to occur in the manufacturing process. The technique can also be used to measure the moisture content of many other dielectric materials, including timber.

A second possible application of the invention is in the measurement of product uniformity. A typical example is a chocolate bar, which may contain a mixture of chocolate and other ingredients. Measurement of the ratio C/G allows product in both the solid and molten state to be monitored to give an indication of uniformity during the production process.

It will be appreciated that the electrodes 1 used can be in plate form or cylindrical electrodes.

A further application of the present invention is in Electrical Capacitance Tomography (ECT). A simple ECT system produces a single set of images which are based on the composite measurement of the loss-free and lossy components of the permittivity of materials placed in the sensor. Such a system is described in UK Patent specification No. 2214640. However, if the known capacitance measuring circuitry is replaced by the circuitry described herein, it is possible to create two separate sets of images, based on the variations in the loss-free and lossy components of the permittivities of the materials inside the ECT sensor. This will allow improved imaging in ECT systems, particularly for more conductive materials.

CLAIMS

1. A method for measuring the impedance of a lossy capacitor comprising the steps of cyclically charging and discharging the capacitor, measuring the current flowing through the capacitor at different times in the cycle to establish values of current resulting from the capacitive component and conductive component of the impedance and converting the said current values into capacitive and conductive components of impedance.

2. A method according to claim 1, wherein the period of the charge or discharge cycle is chosen to be substantially greater than the estimated time required to charge or discharge the lossy capacitor, a first current measurement being made at the beginning of the cycle when the capacitor is being charged or discharged and a second current measurement being made subsequently to determine the residual current flowing as a result of the conductive component of the impedance.

3. A method according to claim 2, wherein the measuring of current at different parts of the cycle is achieved by timed switching of the current flowing between two measuring points so that first current measurement is measured at a first measuring point and the second current measurement is measured at a second measuring point.

4. A method according to any preceding claim, wherein measurements are made during either the charging or the discharging cycle.

5. A method according to any one of claims 1 to 3, wherein measurements are made during both the charging and discharging cycle and compared to minimise errors.

6. A method according to any preceding claim wherein the impedances of two lossy capacitors are compared in parallel.

7. A method for measuring the moisture content of a material comprising the steps of placing the material between electrodes of a capacitor, applying the method of any preceding claim and calculating the capacitance or the conductance of the material.

8. A method for measuring the uniformity of a material comprising the steps of placing the material between electrodes of a capacitor, applying the method of any one of claims 1 to 6 and calculating the capacitance or the conductance of the material.

9. A method according to claim 7 or 8, wherein the ratio of measured capacitance to measured conductance is calculated.

10. An electrical capacitance tomography device comprising means for measuring the impedance of a capacitor using the method according to any one of claims 1 to 6.

11. Apparatus for measuring impedance of a lossy capacitor, comprising means for cyclically charging and discharging the capacitor, means for measuring current flowing through the capacitor at different times in the cycle to establish values of current resulting from the capacitive component and the conductive component of the impedance, and means for converting the said current values into capacitive and conductive components of impedance.

12. A method substantially as hereinbefore described with reference to the accompanying drawings.

13. Apparatus for measuring impedance of a lossy capacitor substantially as hereinbefore described with reference to the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

Relevant Technical Fields	Application number GB 9424803.6
(i) UK Cl (Ed.N) G1U (UR2702, UR2726)	Search Examiner J BETTS
(ii) Int Cl (Ed.6) G01R 27/02. GO1R 27/06	Date of completion of Search 6 MARCH 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE DATABASES: WPI, CLAIMS	Documents considered relevant following a search in respect of Claims :- 1-13

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X	GB 1222963 (EVERSHED AND VIGNOLES)	1,3,4,11
X	EP 0288215 A (SIMMONDS)	1-4,6,11

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

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